

## Majorana Experimental Simulations

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The Majorana experiment will search for neutrino-less double beta-decay and dark matter with 500-kg enriched germanium crystals. Majorana will be a large collaboration spanning decades and requires an accurate, robust, persistent and reliable simulation package that is flexible enough to handle the many different simulation efforts required. LBNL has taken the lead in the development of this package.

The proximity of NERSC facilities and personnel makes LBNL an excellent choice for hosting the development and running of the simulation. The Majorana collaboration foresees to make extensive use of the computing power of PDSF and the storage capabilities of HPSS. Large Linux-based clusters, such as PDSF, are well-suited to the simulation requirements of Majorana, and the simulation of pulse-shapes (see below) will benefit from the storage capacity of HPSS. Majorana has also added members of the High Energy and Nuclear Physics Systems Group (HENP) at NERSC to its collaboration to strengthen the software development and maintenance effort. HENP personnel specialize in developing computing solutions to sophisticated physics problems, such as those posed by Majorana.

Majorana is a sophisticated experiment that has many aspects to be simulated. The collaboration has provided the simulation group with a preliminary list of items to be studied with simulation. These include:

1. The simulation of different segmentation schemes, dead layers, and electric field in the crystal to help optimize the geometry of the crystal.
2. The effect of radioactive backgrounds, including isotopic cascades, and establishing purity requirements for materials.
3. Different packing schemes for the crystal to maximize the discrimination of gamma-rays that Compton scatter between crystal from single site neutrino-less double beta-decay events.
4. Different shielding schemes, such as neutron absorbers, active veto for muons, shielding materials, etc.
5. Muon and neutron interactions in detector, support structures, shields, and rock
6. Simulation of pulse-shape for different processes in the crystals. This is critical for reaching the required reduction in background levels of Majorana.

The simulation begins with a generator that generates a signal event, such as two electrons from a neutrino-less double-beta decay or recoil nucleus from a WIMP-nucleus interaction. Another crucial generator task is to accurately simulate the radiation produced during the decay of radioactive contaminants in the detector bulk and construction material.

Given the initial conditions from the generator, Geant 4<sup>1</sup> simulates the interaction of the generated particles in the

detector and their energy deposits. Geant 4<sup>1</sup> is a popular and detector simulation tool developed at CERN and forms the backbone of the simulation. Geant 4 has powerful geometry descriptions that allows complex geometries to be simulated with high fidelity.

The energy deposits computed by Geant 4 are passed to a custom pulse-shape simulation package that generates the pulse shape each segment would detect and convolutes it with the electronic response of the detector. The simulated data is then saved in a format identical to that produced by the experiment for parallel analysis by the same software.

The code is maintained on a dedicated CVS server at NERSC. It is C++ based and follows the object-oriented design philosophy. Data about the detectors are saved in a PostgreSQL database designed by HENP. Reference documentation for the code is generated by Doxygen, and the user's guide is written in Docbooks. The drift and weighing field for the crystals are generated with a commercial package, Maxwell3D. See figure 1.

The final product will be a stable, well-documented software package, hosted on PDSF, that simulates with high fidelity the Majorana experiment. The package will also integrate all the different R&D studies that went into the design and optimization of Majorana.



Figure 1. The figure on the left shows the electric potential for a 2 segmented closed coaxial crystal with a bias voltage of 4000V, as computed by Maxwell3D. It is used to compute the trajectories of charge carriers in the crystal. The figure on the right shows the so-called weighing potential of one of the segments. It is used to compute the induced current on the segment from the moving charge carriers. The understanding of the induced currents on the segments by simulation will ultimately allow significant discrimination between background gamma-rays that produce multiple interaction sites in the crystal and neutrino-less double beta-decay that produces single interaction sites in one crystal.

## REFERENCES

- [1] <http://geant4.web.cern.ch/geant4>